A linear systems approach to advanced EUV resist characterization

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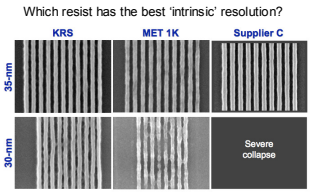
MOTIVATION

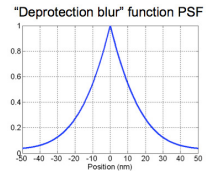
- Resist is one of the biggest challenges facing EUV development
- Problem lies in simultaneous achievement of resolution, LER and sensitivity goals
- While LER and sensitivity are easily quantified, intrinsic resolution often remains subjective



- Which metrics are best for comparing and ultimately quantifying 'intrinsic resolution'?
- Can we extract a resist blur (point-spread) function?

RESIST MODELING BASED ON THE POINT-SPREAD FUNCTION (PSF) METHOD

- PSF resist modeling* is fast and convenient, model easily generated
- Provides intuitive link to resist resolution limit
- Few parameters make model less susceptible to extrapolation errors



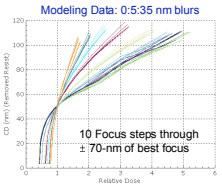
*C. Ahn, H. Kim, K. Baik, "A novel approximate model for resist processes," Proc. SPIE 3334 (1998)

**Gregg Gallatin, "Resist Blur and Line Edge Roughness," Proc. SPIE 5754 (2005)

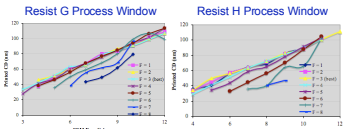
- Resist process well modeled by deprotection blur function**

SENSITIVITY OF CONTACT METRIC

FOCUS - Modeling: generate aerial images through ± 70-nm of best focus and observe changes in CD vs. dose.

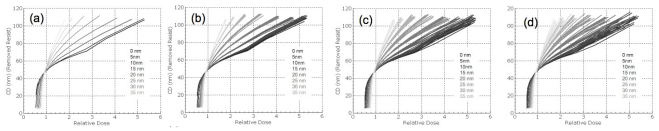


FOCUS - Experimental: observe how CD vs. dose changes through 50-nm FEM focus steps



- Excellent experimental control of focus & picking best focus from FEM; no need for full process window.
- Modeling predicts **Focus-control blur-error ~ 1 nm**

OPTIC ABERRATIONS: a) – d) show 0, 10, 20, and 30% rms noise level lineouts. 10 random aberration maps in each noise level



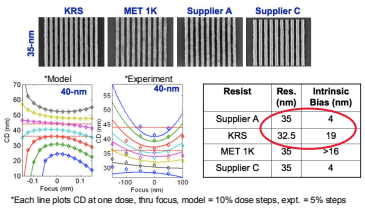
*K. Goldberg, et al. "At-Wavelength Alignment and Testing of the 0.3 NA MET Optic," J. Vac. Sci. & Technol. B *22*, 2956-2961 (2004).

- Error bars from MET optic interferometry ~ 10-20%*
- Repeating this study for the corner metric shows focus and aberration error-bars of 0.91 nm and 2.25 nm respectively**

**C. Anderson and P. Naulleau "Sensitivity study of reliable, high-throughput resolution metrics for photoresists." To be printed J. Vac. Sci. & Technol. B Nov/Dec 2007.

SO,... WHAT DOESN'T WORK?

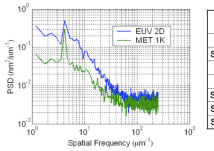
Intrinsic bias – Find CD that remains constant through focus. Compare model and experimental data -> the shift is the intrinsic bias



Resist	Res. (nm)	Intrinsic Bias (nm)
Supplier A	35	4
KRS	32.5	19
MET 1K	35	>16
Supplier C	35	4

*Each line plots CD at one dose, thru focus, model = 10% dose steps, expt. = 5% steps

LER spatial frequency roll-off – What is the spatial frequency cutoff of a line edge? Correlation length (Lc) inversely proportional to cutoff.

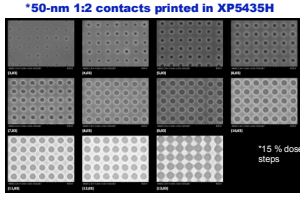


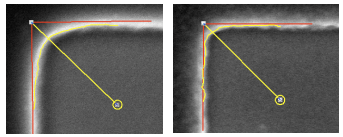
Resist	Res. (nm)	L_c (nm)
EUV 2D	50	24
Supplier A	35	20
KRS	32.5	18
MET 1K	35	22
Supplier C	35	28
Supplier E	35	26
Supplier F	30	25

•Extracted blur not consistent with observed resolution for LER and intrinsic bias metrics

NEW METRICS BEING EXPLORED

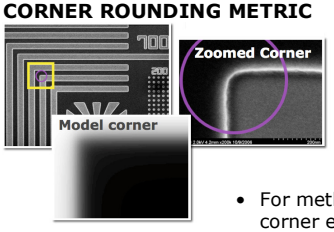
50-nm 1:2 contact printing through dose - Measure printed CD through dose. Compare to modeled CD through dose for aerial images with different levels of deprotection blur.



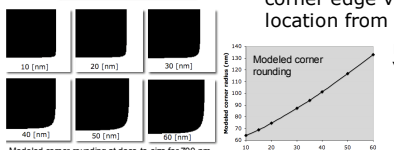


Corner rounding of large features Measure radius of 700-nm elbow corner. Compare to modeled radius for aerial images with different levels of deprotection blur.

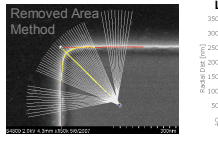
CORNER ROUNDING METRIC

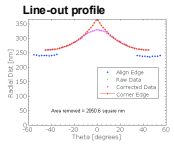


- How to determine 'corner radius'? We've used three methods: 1.) least-squares circle fit, 2.) the curvature method* and 3.) the 'removed area' method.
- We found methods 1 and 2 were subject to errors on experimental data; decided to use in-house 'removed area' method.
- For method 3 we draw radial line-outs to find corner edge vs. θ. We determine the ideal corner location from straight edges and compute the removed area. This determines the 'effective' corner radius.



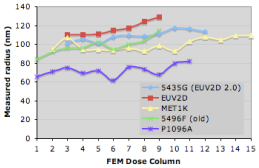
Modeled corner rounding at dose-to-size for 700-nm elbow corners. Deprotection blur is in nm, FWHM





Add random low-order Zernike coefficients fluctuations to MET optic model in varying degrees and observe changes in CD vs. dose (contacts)

•20% RMS aberration uncertainty blur-error ~ 2 nm



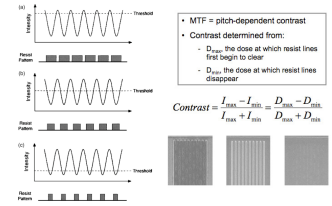
Resist	Res [nm]	Blur [nm]
RHEM EUV-2D	50	47
RHEM MET-1K	35	33
RHEM 5496F	35	34
RHEM XP5435G	45	42
FUJIFILM P1096A	<30	20

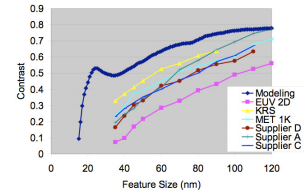
•Extracted blur consistent with observed resolution

*R. Jones, J. Byers "Theoretical Corner Rounding Analysis and Mask Writer Simulation," Proc. of SPIE 5040 (2003)

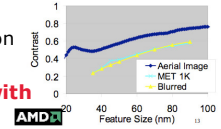
WHAT SEEMS TO HAVE WORKED IN THE PAST?

Resist-based MTF measurements - compare 'resist contrast' to modeled aerial image contrast. Blur modeled aerial image with a PSF until it's contrast vs. CD curve matches experimental data.





•MET1K: Modeled aerial image blurred with 21-nm HOST function matches experimental data.

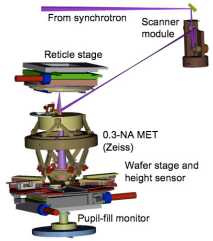


Resist	Res. (nm)	Blur (nm)
EUV 2D	50	54
Supplier A	35	29
KRS	32.5	17
MET 1K	35	25
Supplier C	35	26

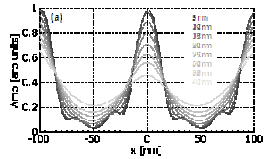
•Extracted blur consistent with observed resolution

50-nm CONTACT METRIC

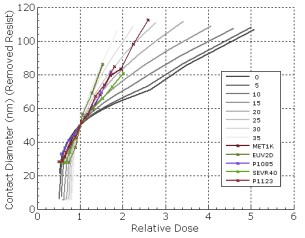
- **Data collection** - All experimental images are collected at the SEMATECH Berkeley MET using 0.35 <σ <0.55 annular illumination
- Aerial images with varying degrees of blur show degrading effective resist latent image



Aerial image cross-section: 50-nm 1:2 contacts with varying degrees of deprotection blur



Reported CD is the average of the same 20 central contacts in the 50-nm 1:2 contact array



- Metric can be viewed as inverse Fourier equivalent to MTF method

Resist	Res [nm]	Blur [nm]
RHEM EUV-2D	50	33.12
RHEM MET-1K	35	24.5
TOK EUVR-P1123	27	23.23
TOK EUVR-P1085	25	21.80
Resist J	20	16.49

•Extracted blur consistent with observed resolution

SUMMARY

- Two new PSF-based metrics for EUV resist testing developed; both appear to give a good measure of intrinsic resolution.
- Focus and aberration sensitivity study shows ~ 2-nm error bar in extracted blur for both corner and contact methods.
- Additional testing lower-blur resist platforms needed to verify fidelity of corner and contact metrics at lower intrinsic blurs.
- Both metrics require < 10 SEM images through dose.

Acknowledgements

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